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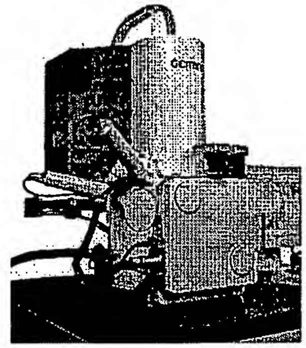
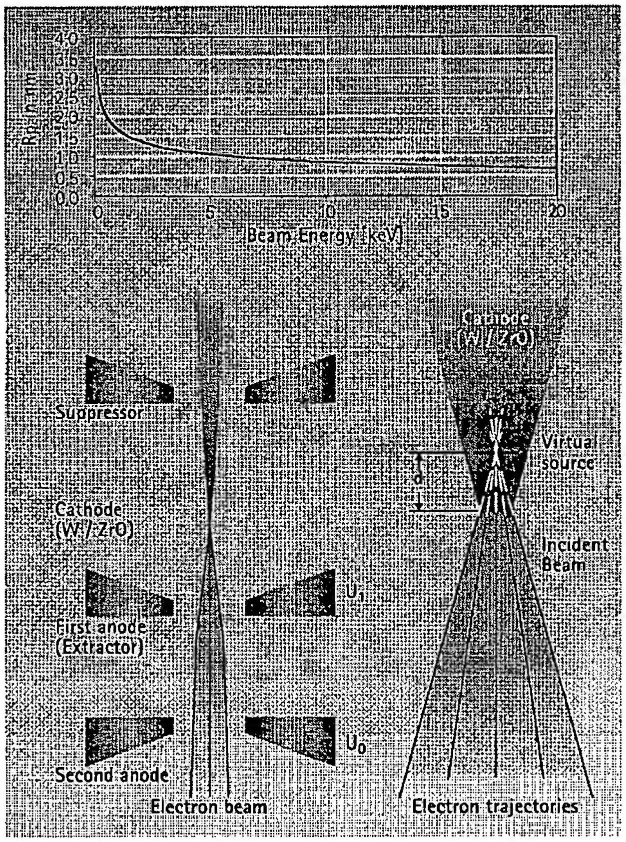
GEMINI field emission electron optics: core technology for the LEO SUPRA range



Advanced SFE

The Schottky field emission (SFE) source used in the LEO GEMINI column has been developed to overcome the weaknesses of the cold field emission (CFE) source, whilst maintaining its strengths in the form of high beam brightness and low energy spread. Because of their many advantages, Schottky emitters are used for high precision imaging and measurement. The table below shows the operating parameters and performance of various electron gun types.

The Schottky emitter combines the high brightness and low energy spread of the cold field emitter with the high stability and low beam noise of the thermal emitters. As the emitting area is approximately 100 times larger than that of the cold field emitter, it has the capability to deliver much higher probe currents required. Moreover, the SFE source achieves a similar energy spread as the CFE source, but at an emission current level more than 50 times higher. The larger size of its virtual source gives the SFE source another advantage: its susceptibility to vibration is much reduced.



The high brightness SFE source combined with the innovative GEMINI column enables the small spot sizes for ultra high resolution combined with high contrast and high probe currents.

Due to the direct link of the SFE gun with the beam booster, the dynamic ratio at the gun level is only about 3:1 and the U_0/U_1 ratio is always larger than unity. This allows a column beam path without any intermediate cross-over of electrons. The classical designs are therefore prone to electron energy broadening in beam cross-overs and have difficulty operating at the very low beam energies which are now increasingly required for many applications.

The SFE incorporated in the GEMINI column provides excellent beam brightness, unsurpassed probe current stability and probe current suitable for quantitative analytical applications.

Electron Source Performance Comparison				
Emitter type	thermionic	thermionic	cold FE	Schottky FE
Cathode material	W	LaB_6	W (310)	ZrO/W (100)
Operating temperature [K]	2,800	1,900	300	1,800
Cathode radius [nm]	60,000	10,000	≤ 100	≤ 1,000
Effective source radius [nm]	15,000	5,000	2.5 (a)	15 (a)
Emission current density [A/cm²]	3	30	17,000	5,300
Total emission current [µA]	200	80	5	200
Normalised brightness [A/cm² sr kV]	$1 \cdot 10^4$	$1 \cdot 10^5$	$2 \cdot 10^7$	$1 \cdot 10^7$
Maximum probe current [nA]	1000	1000	0.2	10
Energy spread at the cathode [eV]	0.59	0.40	0.26	0.31
Energy spread at the gun exit [eV]	1.5 – 2.5	1.3 – 2.5	0.3 – 0.7	0.35 – 0.7
Beam noise [%]	1	1	5 – 10	1
Emission current drift [%/h]	0.1	0.2	5	< 0.5
Operating vacuum [hPa]	$\leq 1 \cdot 10^{-5}$	$\leq 1 \cdot 10^{-6}$	$\leq 1 \cdot 10^{-10}$	$\leq 1 \cdot 10^{-8}$
Cathode life [h]	200	1000	2000	2000
Cathode regeneration	not required	not required	every 6 to 8 h	not required
Sensitivity to external influence	minimal	minimal	high	low

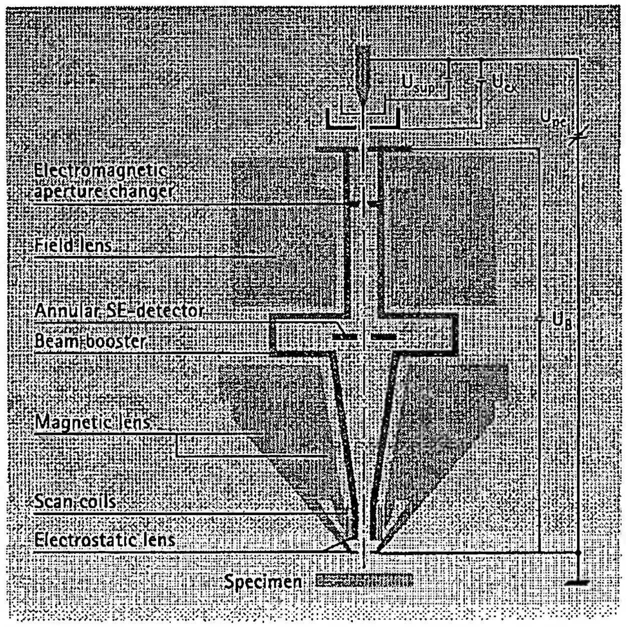
(a) virtual source

Electron Source Performance Comparison

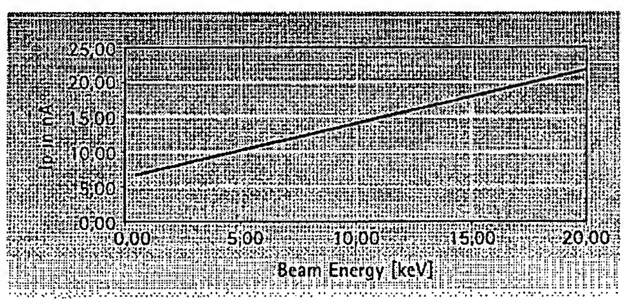
Innovative electron optical column

GEMINI

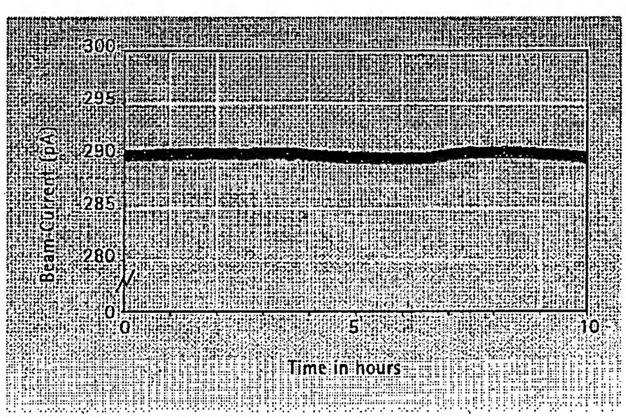
A beam booster is an integral part of the GEMINI electron optical column. The beam booster always maintains a high beam energy throughout the entire column, regardless of the electron beam energy selected by the operator. Only after passing through the scanning system the electron beam is decelerated to its selected landing energy. The electron beam path has been designed to eliminate cross-over of beam electrons between source and specimen. Furthermore, the high beam energy throughout the column ensures that the GEMINI column is extremely well protected against magnetic stray fields, even when operated at very low voltages. The tolerable magnetic stray field limit is therefore independent of the selected voltage.
An electromagnetic, multi-hole aperture changer has been incorporated close to the electron source. In combination with a magnetic field lens to select the optimum beam aperture angle and to tune the probe current.
The combination of the high beam energy and cross-over free electron beam path also minimize the statistical Coulomb interactions between beam electrons, which tend to reduce the brightness and hence the resolution limit of the microscope. As a result, the LEO SUPRA GEMINI column always provides optimum beam brightness, especially when needed at the lowest electron probe energies.



Operating principle of the LEO GEMINI field emission column.
U_1 - extractor voltage at first anode
U_0 - accelerator voltage at second anode
U_B - booster voltage



Probe current in nA related to landed beam energy.

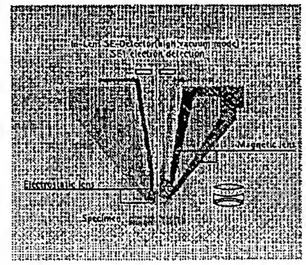


Ultra high stable GEMINI electron optics.

In the LEO GEMINI column the electron beam rays only intersect once: at the focusing point on the specimen surface. Therefore, the broadening of beam energy spread, a problem with all electron optic configurations featuring one or more intermediate cross-over – irrespective of the electron source – has been completely eliminated. This is especially significant when ultra high resolution is needed at low voltage applications.

The innovative GEMINI column concept provides superior beam brightness with ultra high resolution over the complete voltage range together with high probe currents for analytical applications.

Ultra-high performance objective lens



GEMINI

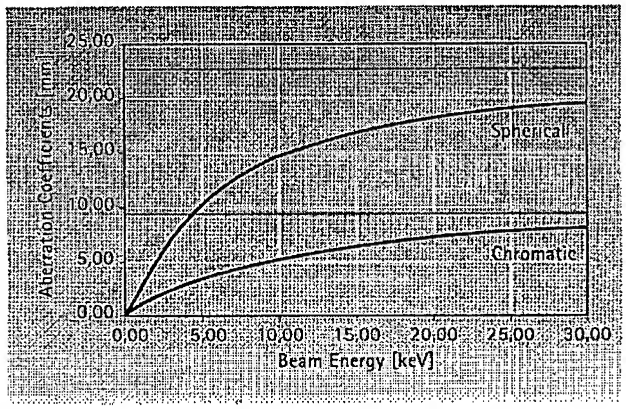
The LEO SUPRA has been built around the unique GEMINI lens design which has many advantages over classical lens designs:

The most important feature is the decreasing aberrations with decreasing beam energy. Therefore it delivers superb resolution down to 100 eV and at 30 keV its resolving power is unsurpassed.

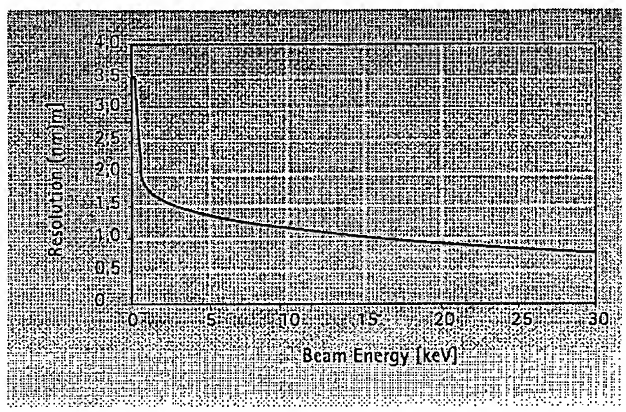
The high-angled GEMINI objective lens body allows 50° tilt of large specimens (e.g. 6" wafers) at a working distance as low as 6 mm. The analytical working distance for EDS analysis with a take off angle of 35° is only 8.5 mm - suitable for high resolution imaging.

The GEMINI objective lens consists of a high-performance magnetic lens with an inserted electrostatic lens. The GEMINI concept has overcome the problem with classical objective lens designs which immerses the specimen in the magnetic field prohibiting imaging of magnetic samples.

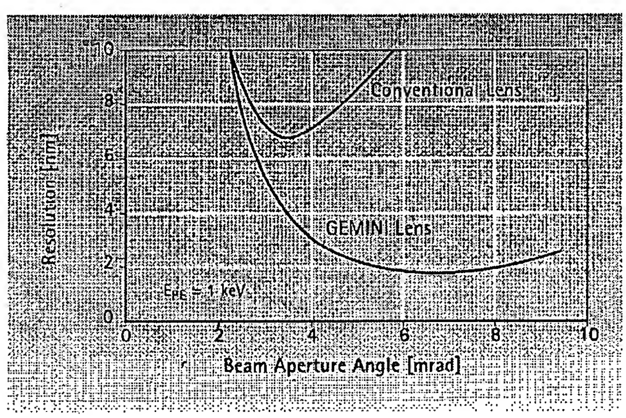
The GEMINI magnetic lens is shaped to minimise the magnetic field at the specimen. Therefore high resolution imaging of dia-, para-, or ferromagnetic samples is possible with very short working distances.



Dramatic reduction of objective lens aberrations at low in the low kV range.



Improvement in image resolution at an accelerating voltage of 1keV due to the increased beam aperture.



Guaranteed image resolution on test sample

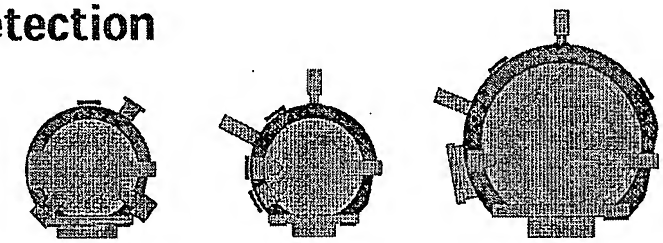
The magnetic/electrostatic lens combination is equivalent to an optical lens triplet which increases the incident beam aperture angle at the specimen and hence improves resolution. The increase of the optimum beam aperture angle also provides a larger electron probe current and hence generates a superior signal to noise ratio of the image.

The lens control system with integrated condenser control will always select the optimum beam aperture for any working distance and / or selected energy. Consequently the LEO SUPRA delivers excellent image contrast even at the resolution limit.

A single-stage beam scanning system is integrated in the GEMINI lens, just in front of the electrostatic lens gap. Therefore, the transverse chromatic and other scanning aberrations have been minimised. The instrument operates without distortion at TV-scanning speed from the lowest (20x) to the highest (900,000x) magnification. In particular, no switchover is required between a low magnification mode and a high resolution mode.

The GEMINI objective lens provides outstanding resolution and image quality, especially at low beam voltages without any compromise in operational convenience.

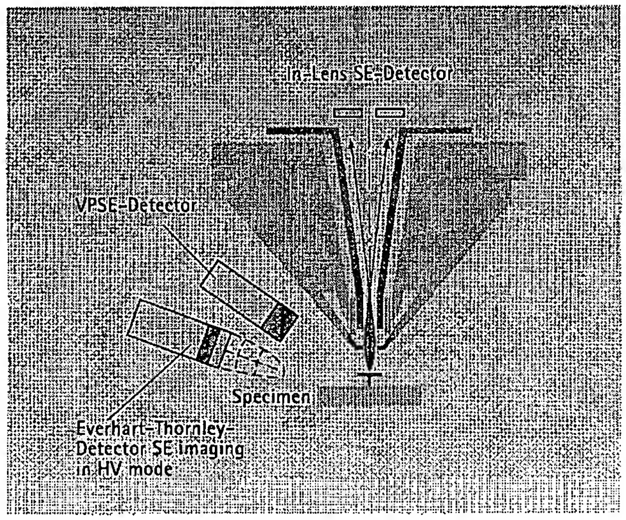
High efficiency SE signal detection



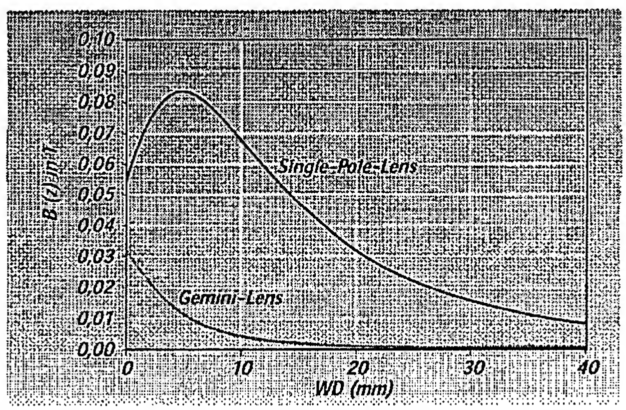
SE

Excellent efficiency detection of the secondary electron (SE) signal is another benefit of the GEMINI lens concept. The low-energy, secondary electrons generated at the impact point of the primary electron beam are intercepted by the weak electrical field at the sample surface, then accelerated to a high energy by the field of the electrostatic lens and focused on the annular In-lens detector inside the beam booster located above the objective lens. The GEMINI column used with the SUPRA range of FE-SEMs now benefits from the 3rd generation of In-lens detectors with increased signal to noise ratio, improved dynamic range and no aging effect on the detection material. While the In-lens detector provides the best high resolution information, a lateral SE detector in the specimen chamber provides optimum topographical information. Signals from both detectors may be mixed to deliver optimum image quality.

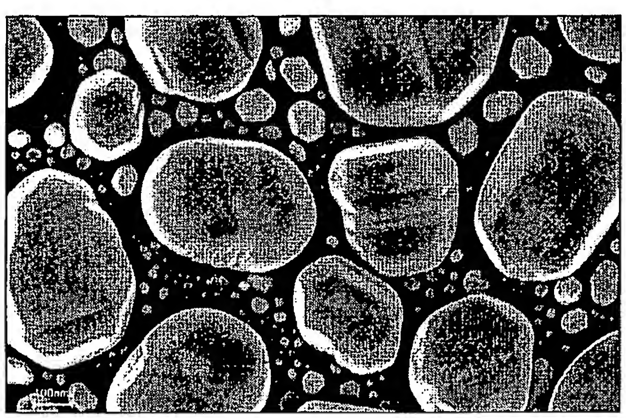
For the variable pressure (VP) instruments LEO has developed a unique VPSE-detector to enable SE imaging at pressures in the 2 to 133 Pa range combined with the standard Everhart-Thornley detector for imaging in high vacuum (HV) mode.



Principle of secondary electron signal detection with the high efficiency In-lens detector and the lateral detector in the sample chamber.



The extremely low magnetic field of the GEMINI column, compared to single pole FESEM instruments, allows distortion-free high resolution imaging of magnetic materials at short working distances.



The LEO GEMINI column allows optimum detection of backscattered electrons (BSE) because of the absence of an immersion field of the objective lens. Classical FE columns tend to condense the BSE on the optical axis in the same way as it condenses the primary electrons. With the GEMINI column a high probe current can be focused on a small spot, even at low beam energies, allowing BSE images and X-ray mapping with much better resolution than ever before.

The GEMINI objective lens concept allows optimum detection of all signals generated at the specimen.

In-lens high resolution SE image at 5 kV.

GEMINI Innovative electron optical column

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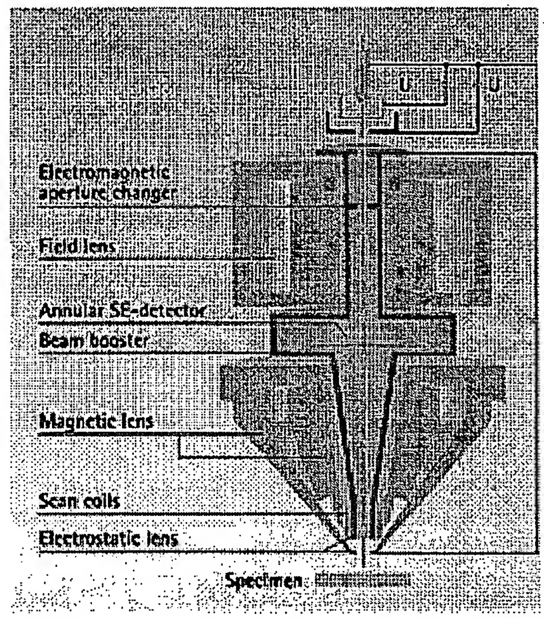

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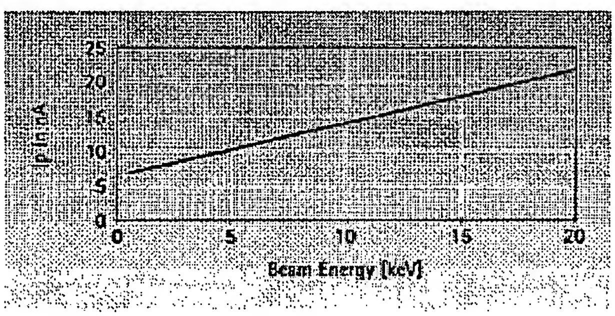

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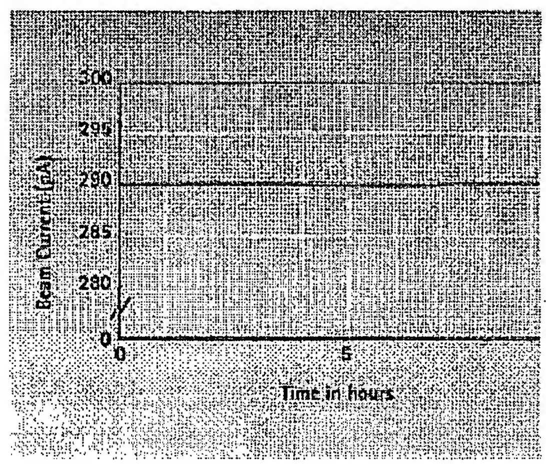

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